

NDE and Advanced Actuators for Space Applications at JPL

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What is NDEAA?

Nondestructive Evaluation and Advanced Actuators

R&D FOCUS AREAS

Mechanisms and devices that are driven by acoustic or elastic waves.

	Small amplitude	Large amplitude
Low frequency (KHz)	Sono-tomography	Actuation
High frequency (MHz)	NDE & diagnostics	Medical treatment



JPL's NDE & Advanced Actuators (NDEAA) Group

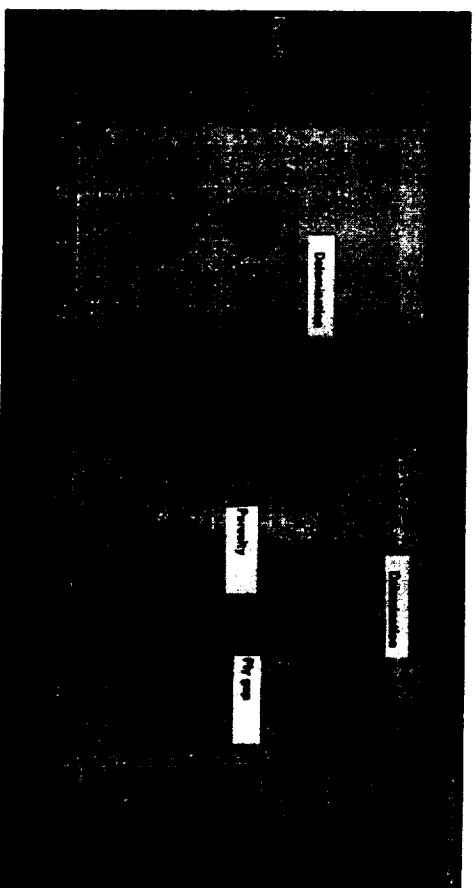
TOPICS OF R&D

- **NDE**
 - Materials properties and flaws characterization using leaky Lamb waves (LLW) and polar backscattering
- **Advanced Actuators**
 - Low Mass Muscle Actuators (LoMMAs) using electroactive polymers
 - Ultrasonic motors (USM) and piezopumps
- **Ultrasonic Medical Diagnostics and Treatment**
 - High power ultrasound (FMPUL)
 - Acoustic Microscopy Endoscope (200MHz)
- **TeleRobotics**
 - Multifunction Automated Crawling System (MACS) and autonomous scanner platforms
 - Noninvasive geophysical probing system (NGPS) for Mars exploration, gas pipes and coal-mines
 - Ultrasonic and coring for planetary exploration

Ultrasonic Leaky Lamb Wave* NDE Method

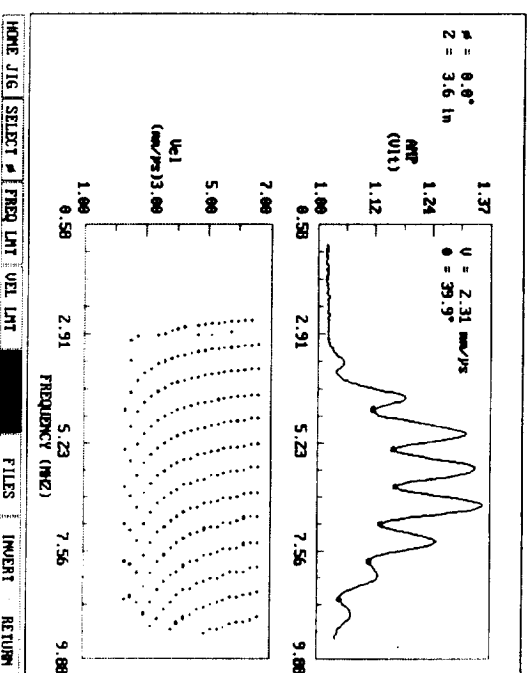
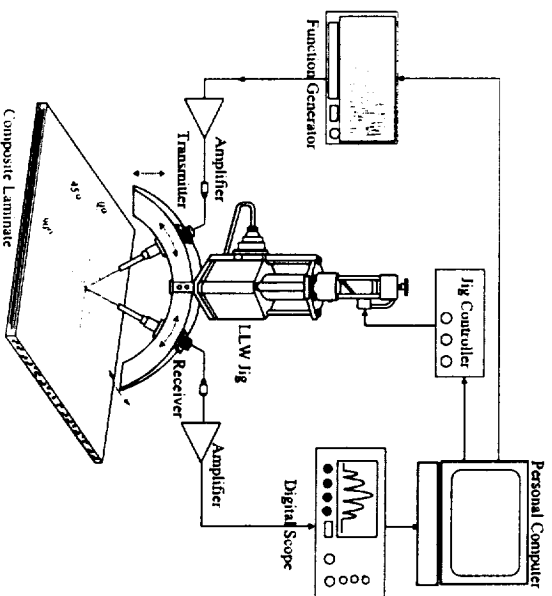
- Very good agreement between theoretical analysis and experimental data
- An efficient setup was developed for data acquisition
- An inversion algorithm was developed to allow determination of the elastic constants
- Method was applied to NDE of defects imaging and characterization

LLW C-scan of [0]₈
Gr/Ep Laminate



* Phenomenon discovered in composite materials by Y. Bar-Cohen in Aug. 1982

Leaky Lamb Wave (LLW) Test System



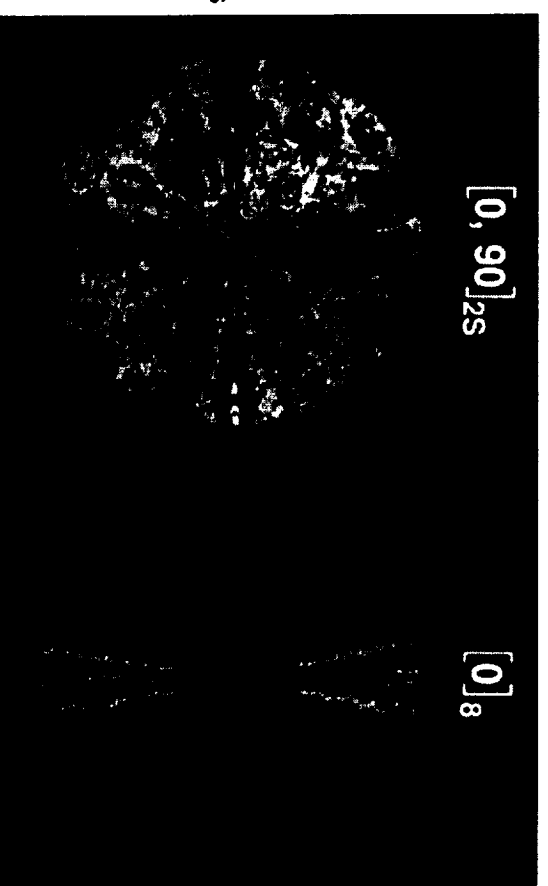
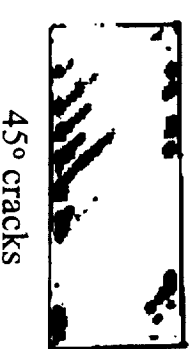
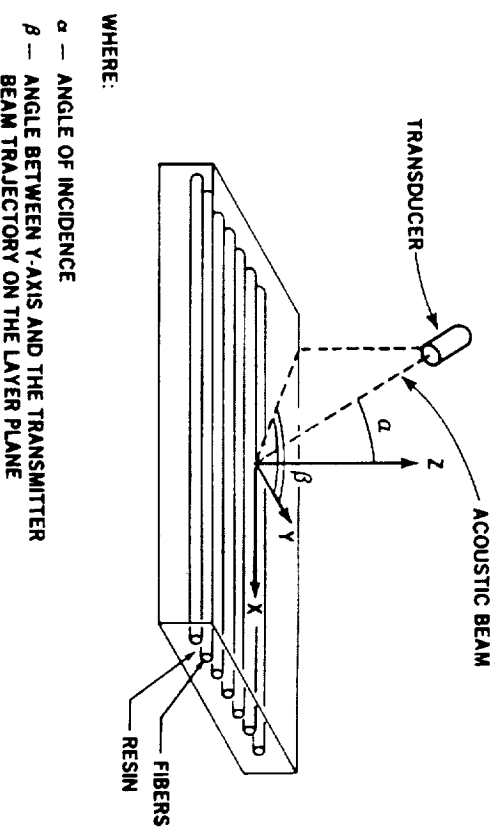
LAMINATE PROPERTIES

E_{11} (GPa)	157.7700
E_{22} (GPa)	10.8200
G_{12} (GPa)	7.9820
G_{23} (GPa)	3.6367
ν_{12}	0.3374
ρ (gm/cc)	1.5780
C_{11} (GPa)	162.7290
C_{22} (GPa)	14.5270
C_{12} (GPa)	7.3590
C_{23} (GPa)	7.2500
C_{55} (GPa)	7.9820



ULTRASONIC POLAR BACKSCATTERING*

Preferred scattering characteristics of discontinuities allows to perform unique imaging of their configuration



Imaging of fiber orientation

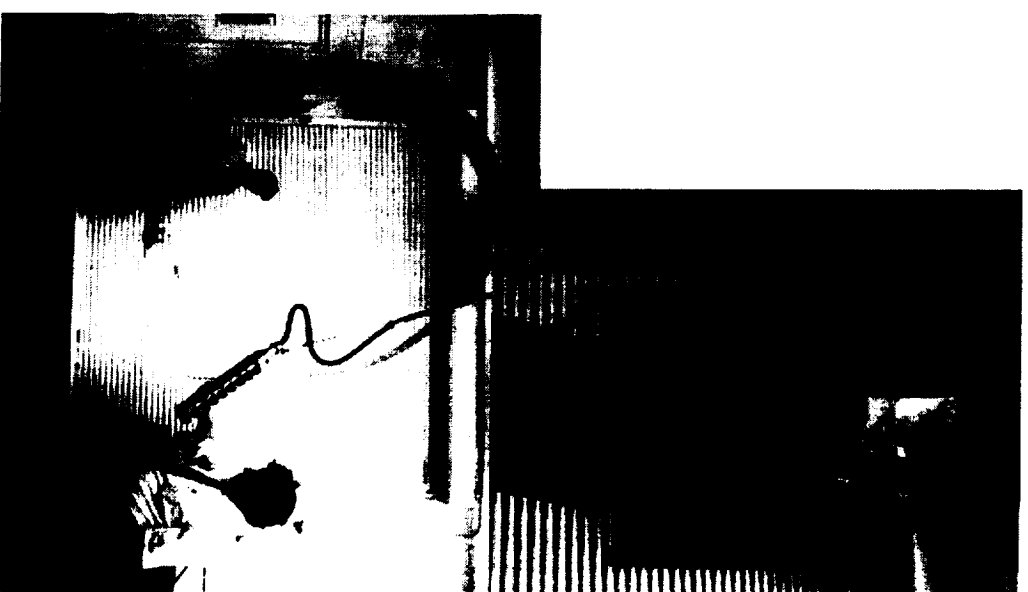
* Phenomenon discovered by Y. Bar-Cohen in Sept. 1979

Multifunction Automated Crawling System (MACS)

MACS is a miniature crawler that forms an enabling technology for automated NDE and maintenance.

It has the following characteristics:

- Operation in any position including mounting vertically and attached upside down.
- Designed to allow rotation on the spot upon a command from the control system
- Ability to move on complex shape structures.
- Effective carrying capability of about 1:10 weight ratio.
- A large carrying platform.

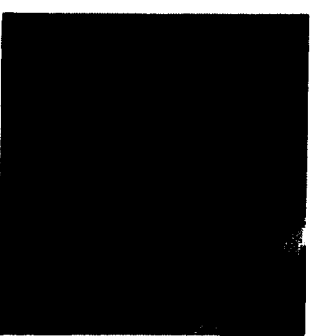


HIGH POWER ULTRASOUND TREATMENT

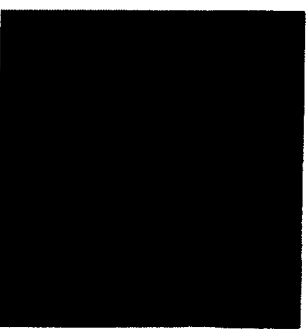
JPL/CSMC/QMI Frequency Modulated high Power Ultrasonic (FMPUL) METHOD

Angiographic example of the effect of transcutaneous ultrasound on the left iliofemoral artery of a rabbit.

Blocked artery



Recovered artery after
30 minutes of treatment



Flash photography dark-field view of cavitations
formed in water using high power ultrasound.





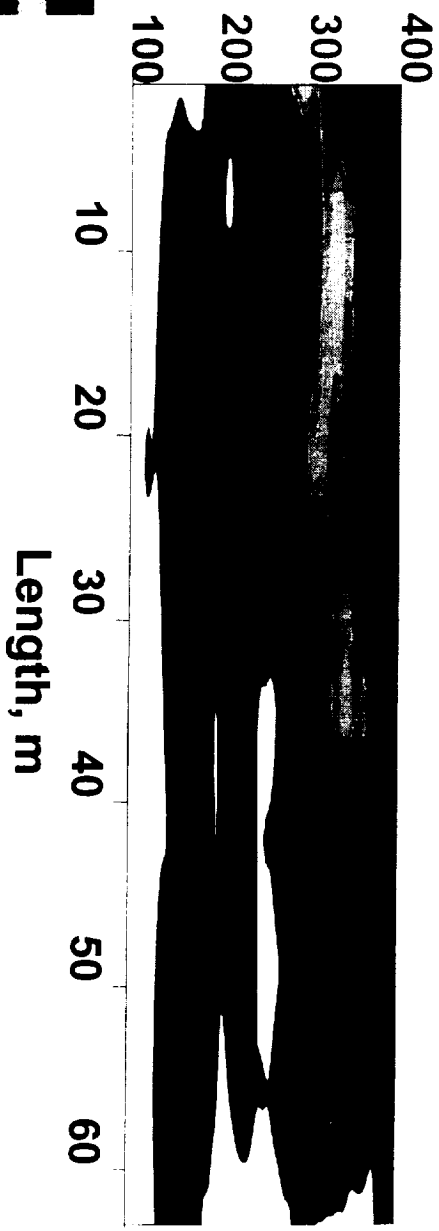
JPL

COAL LAYERS AND MINES STATE-OF-STRESS EXAMINATION USING NON-INVASIVE SURFACE WAVE MEASUREMENTS

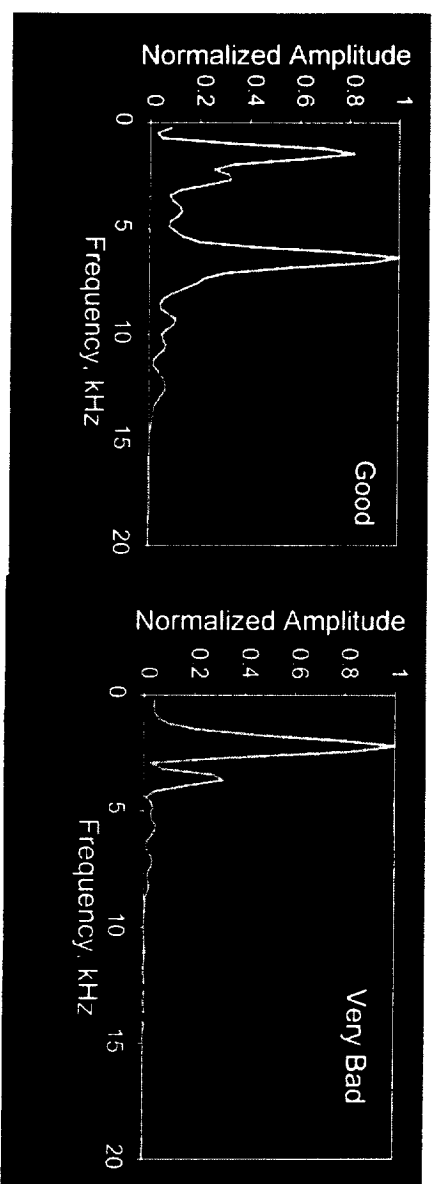
Ultrasonic cross
section imaging of
a bridge slab



Thickness, mm



Ultrasonic
response from two
typical areas of a
tested bridge



ULTRASONIC ROCK DRILLING



UT drilled holes

Flexible drilling wire

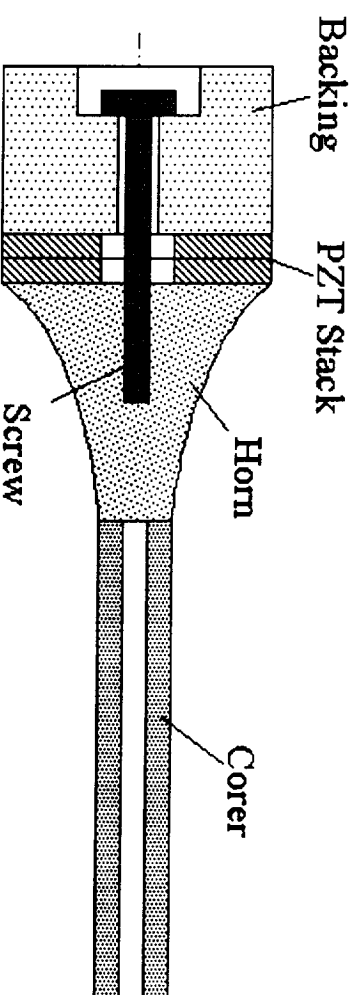
MINIATURE LOW-POWER ULTRASONIC CORE DRILLER (UTCD)



Ultrasonically drilled rocks



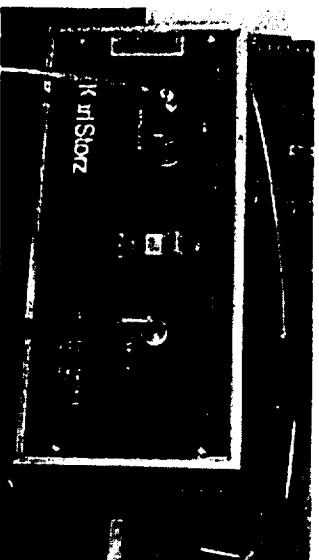
Actuator and sting



General view of the corer actuator and end effector



Corer finite element modeling



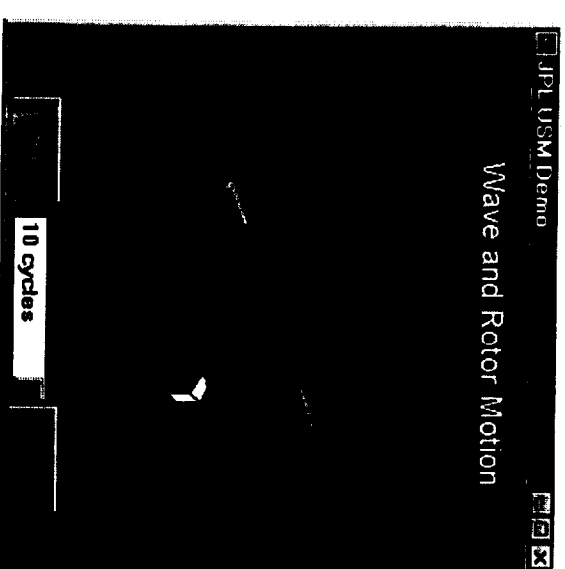
Lithotripsy unit with actuator and sting

Ultrasonic motors (USM)

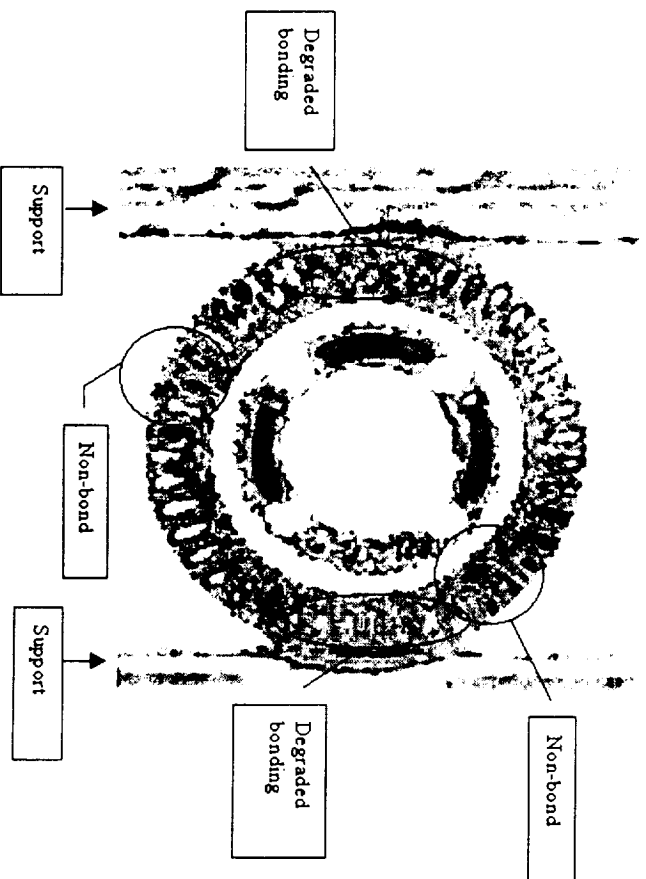
Ultrasonic motors are driven by traveling flexure waves induced by a ring-shape sequentially-poled piezoelectric wafer(s).

JPL progress

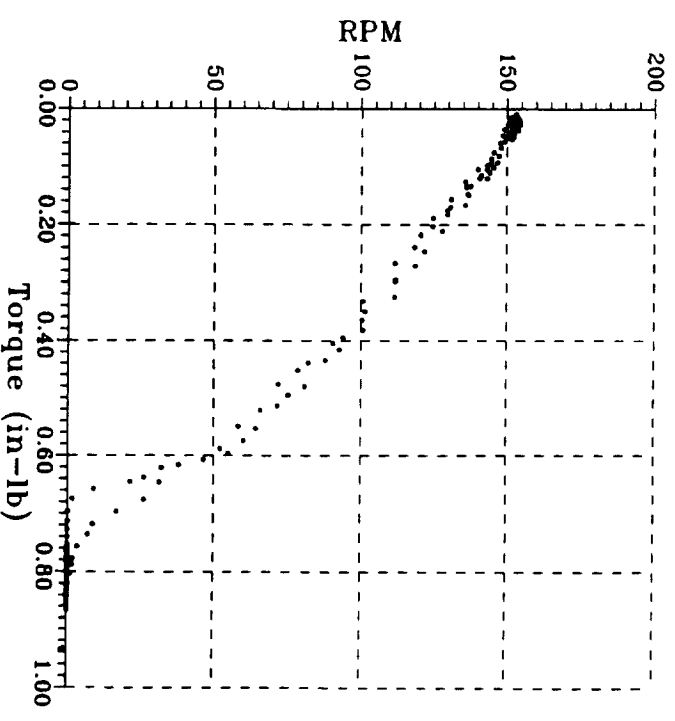
- USMs are analytical modeled for efficient design and for operation in cryovac conditions.
- Experimental setup developed for investigation of the cryovac performance.
- USM were made with segmented and reversed wafers (patent pending).
- Miniature drive electronics is developed.
- The JPL's USM were shown to operate more than 5 times longer than the leading commercial USMs.
- Technology transfer to two major corporations for mass production applications is currently in advanced phases.



Cryovac response of USMs



An Ultrasonic C-Scan image of a 1.2" diameter stator (Shinsei) that was subjected to 150°C and 16 mTorr for over 67-h.



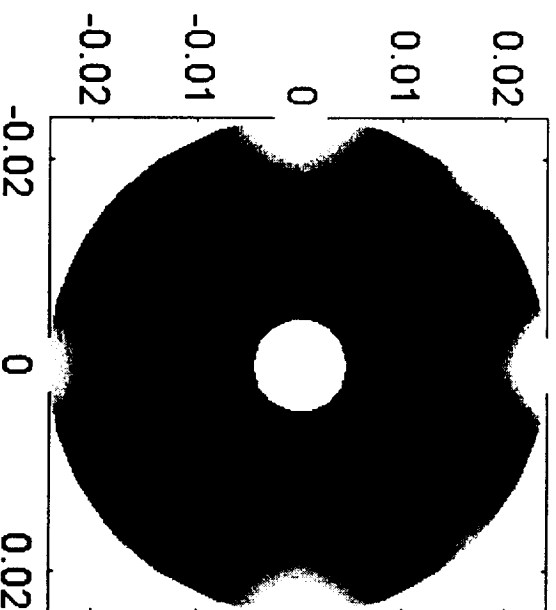
Torque-speed performance of a JPL/QMI USM subjected to 150°C and 16 mTorr (lasted 336 hours)

FINITE ELEMENT ANALYSIS OF USM

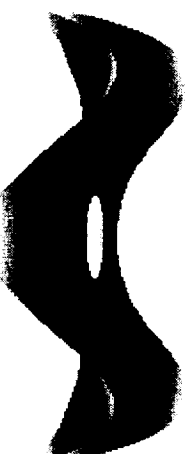
- Finite element model was developed to analyze the behavior of ultrasonic motors in response to various design configurations.
- Predictions of the frequency response of USM's stators were corroborated experimentally at MIT using an interferometric system.

a. Theoretical prediction

Mode(4,0), 14.88KHz



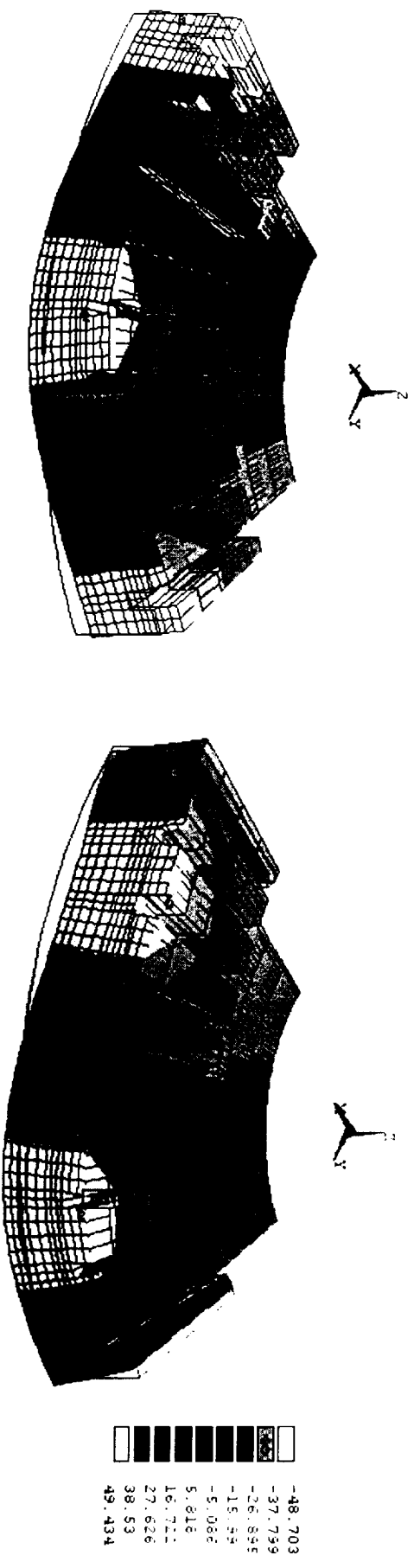
Mode Shape



b. Experimental result



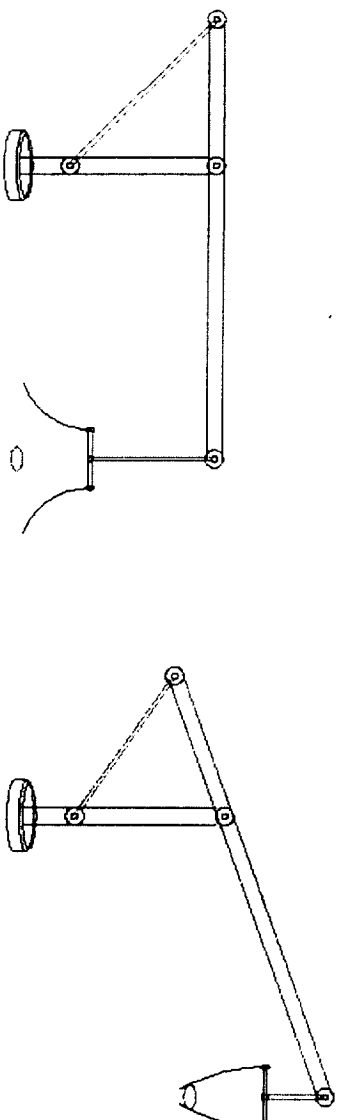
Detailed Modeling Using ANSYS FEM Analysis



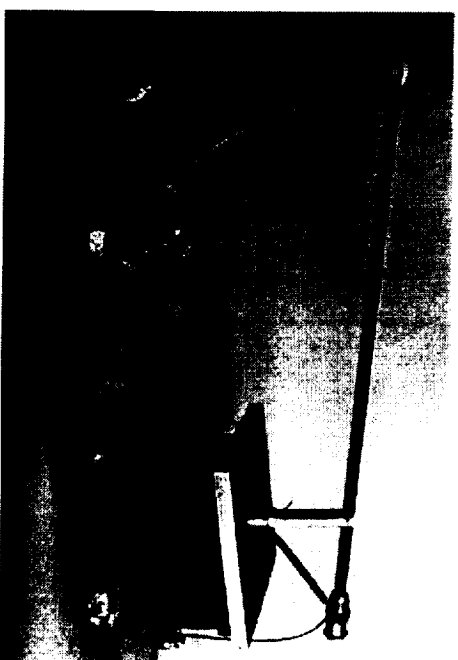
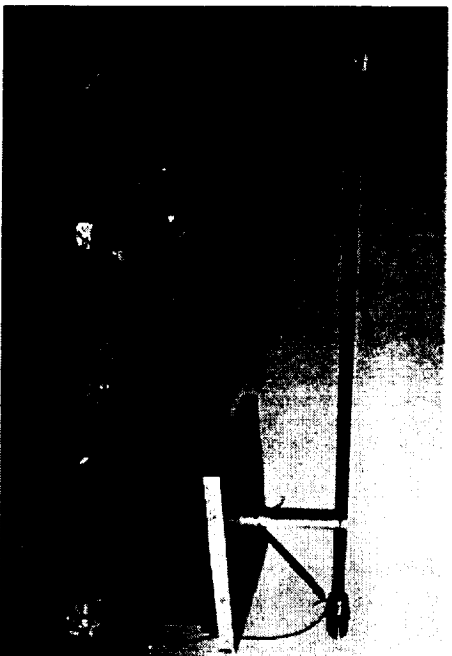
Motor wave travel of $1/4 \lambda$

ELECTROACTIVES POLYMERS (EAP) SAMPLE HANDLING AND MANIPULATION

EAP Robotic arm

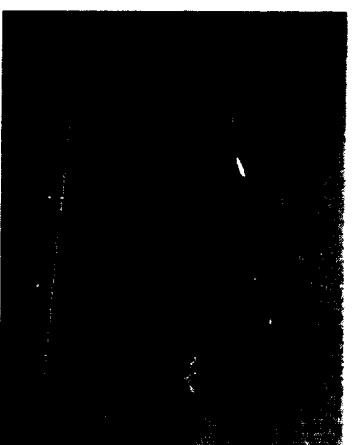
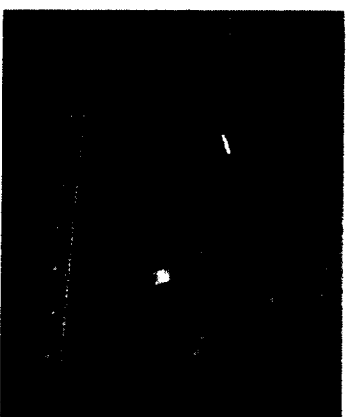


Lifter

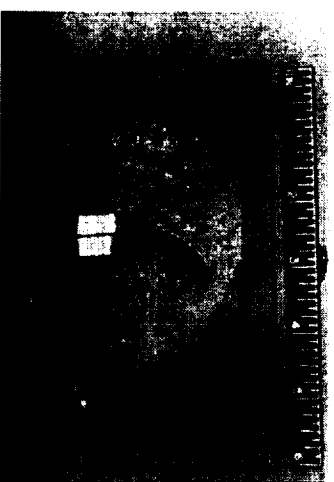


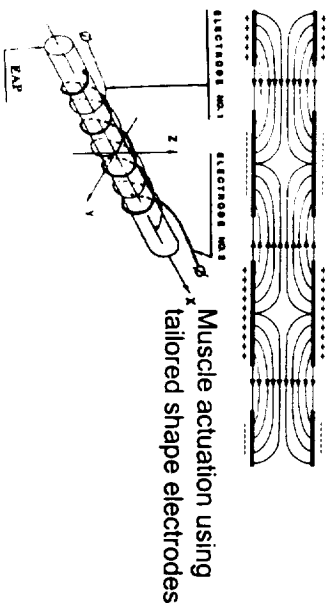
APPLICATIONS OF BENDING EAP ACTUATOR

Gripper



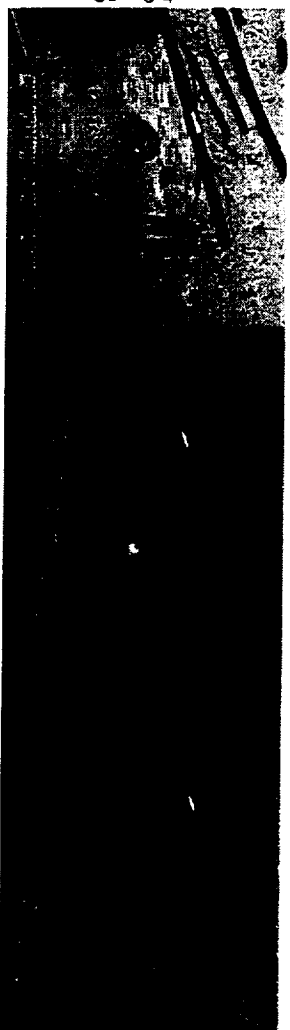
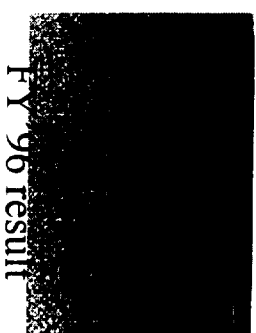
Wiper



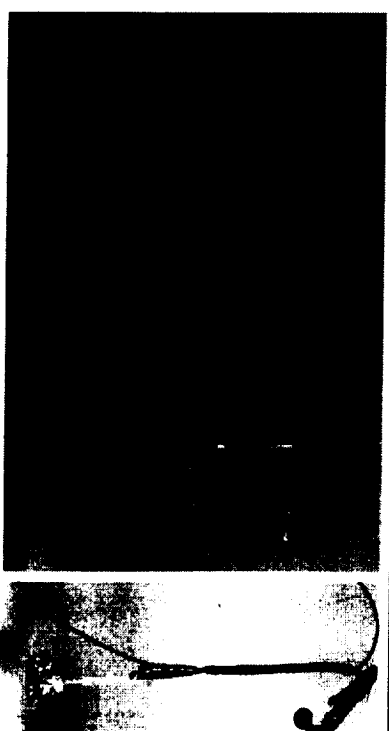


Gripper using bending
EAP fingers

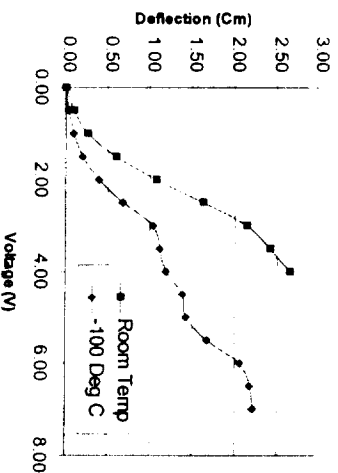
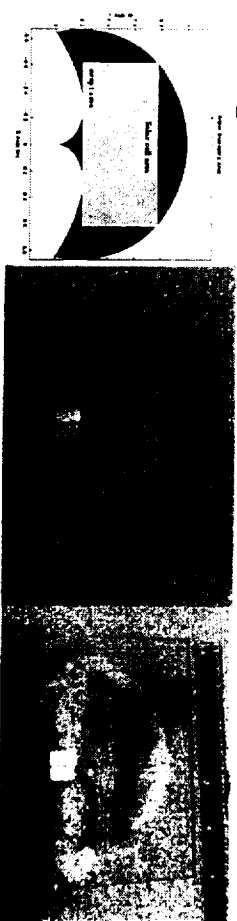
Low Mass Muscle Actuators (LoMMAs)



Longitudinal EAP lifter using
scrolled rope



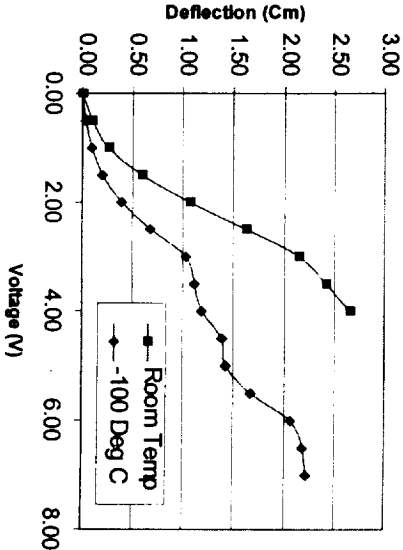
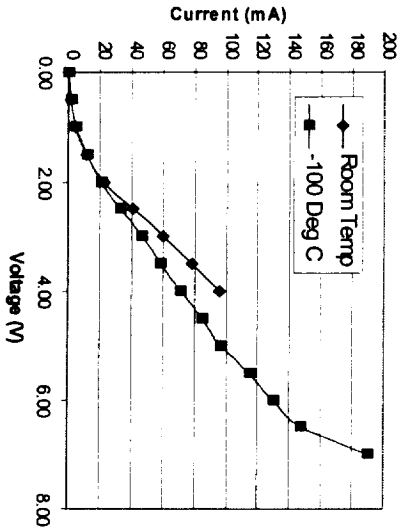
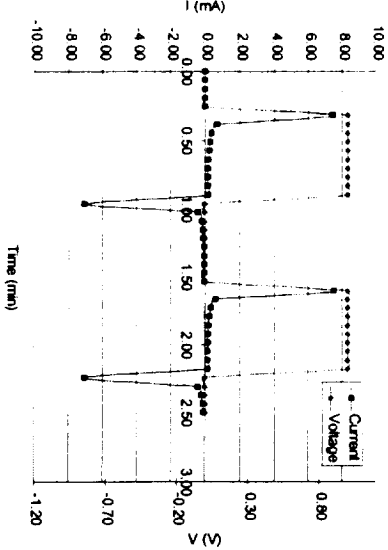
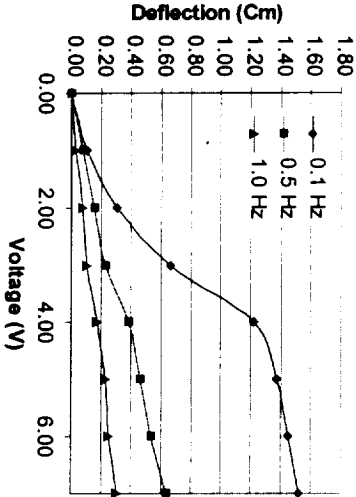
Surface wiper



Deflection vs. voltage at RT and -100°C.



IPMC - EAP BENDING ACTUATOR



Charging capability

Higher resistance at Low Temp

Response at Cryovac

EAP STATUS

- Electroactive Polymers are emerging as effective displacement actuators.
- These materials offer the closest resemblance of biological muscle potentially enabling unique capabilities changing the paradigm about robots construction.
- Under the NASA's LoMMAs task, JPL developed a series of devices that are driven by EAP including dust wiper, gripper and robotic arm
- EAP are inducing a low actuation force limiting the applications that can use their current capability
- In recognition of this limitation two annual conferences were established: SPIE (March) - covering actuators and applications and MRS (Dec.) - materials science.
- A challenge was posed to the EAP community to have an arm wrestling between robot that is equipped with EAP actuators and human.